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Research article

Education and knowledge determine preference for bark beetle control measures in El Salvador

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ABSTRACT

Extensive outbreaks of bark beetles have affected not only large parts of coniferous forests in the Northern Hemisphere, but also — largely absent from global attention — native pine forests of Central America. As such outbreaks frequently spark management debates among residents, land managers, forest owners and the public, the social acceptance of bark beetle control measures has become crucial for modern land management. However, the sociological and psychological determinants of the preference for specific bark beetle control measures outside protected areas remain unclear. To determine the acceptability of bark beetle control measures in El Salvador, we assessed how demographic variables, attitude towards the bark beetle, education, and self-reported knowledge affected the preference for different bark beetle control measures in a survey of government employees and local forest owners using a quantitative questionnaire survey. Cumulative link mixed models revealed that the general preference for control measures increased with increasing self-reported knowledge about the bark beetle but decreased with increasing level of respondent education and an increasing positive attitude towards the bark beetle. Respondents generally preferred beetle control measures on small areas than on large areas. Preferences for control measures did not differ between government employees and forest owners, with controlled burning and chemical control significantly less accepted than stand thinning or salvage logging. We discuss the most preferred control measures considering recent scientific evidence of their efficacy and conclude that the current bark beetle outbreak should be controlled through logging of pines weakened by fire in the short-term and by stand thinning in the medium-term to prevent further outbreaks.

1. Introduction

Northern Hemisphere forests are subjected to an increasing frequency and intensity of natural disturbances, including wildfires (Jolly et al., 2015), windstorms and outbreaks of insect pests (Seidl et al., 2014). Particularly bark beetle outbreaks have led to extensive defoliations in North America and Europe (Nikiforuk, 2011). Also, the native pine forests of Central America have been repeatedly affected by extensive outbreaks of pine beetles, but the occurrences have largely not received public and scientific attention (Billings et al., 2014). For instance, an outbreak of the southern pine beetle (*Dendroctonus frontalis*) in 1962–1965 affected more than 2 million hectares in Honduras, with an estimated spreading rate of 150,000 ha per month (Hernández Paz, 1975). Starting in 2015, a bark beetle outbreak affected native pine forests in El Salvador (MARN, 2016).

While dense green forests have important symbolic and aesthetic value for most people (O'Brien, 2006), forest disturbances are commonly perceived as chaotic, untidy and catastrophic (Flint et al., 2009). Different control measures have been developed to decrease populations of bark beetles, such as salvage logging (i.e. cutting and removing beetle-affected trees), controlled burning, cut-and-leave strategies, chalking and the application of surface-active insecticides (Müller et al., 2018; Vega and Hofstetter, 2015). Decision-making that incorporates such control measures following forest disturbance is often rapid, with long-lasting ecological impacts (Lindenmayer et al., 2004; Thorn et al., 2018). Not surprisingly, their application receives mixed support and level of trust by the different stakeholder groups, such as residents, policy makers, forest owners and land managers, and by the general

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public (Lindenmayer et al., 2008; McFarlane et al., 2015). Hence, the social acceptance of different bark beetle control measures has become crucial for sustainable decision-making by land managers and policy makers (Burton et al., 2006; Sheppard, 2005).

People's perceptions of and attitudes towards natural disturbances and bark beetles, and their support for bark beetle control measures are typically coupled with changes in landscape structures and perceptions of social and economic risks (Carroll et al., 2006; Flint, 2007; Müller, 2011; Parkins and McFarlane, 2015). Consequently, preferences for bark beetle control measures depend on different sociological and psychological aspects, including risk perception (McFarlane et al., 2008), sentiments towards forests affected by bark beetles (Müller, 2011), value orientation (Clement and Cheng, 2011), and the general attitude towards the bark beetle (Flint et al., 2009). A positive attitude towards the bark beetle is correlated with increasing level of education, high level of knowledge of the bark beetle, and a pro-environmental world view; a negative attitude corresponds to the perceived importance of the bark beetle issue (McFarlane et al., 2006; Müller and Job, 2009). In addition, landowners whose forests are used for income or investment and/or for scenic or environmental reasons are more willing to participate in bark beetle prevention (Watson et al., 2013). However, a comprehensive understanding of the determinants of the social acceptance of different control measures is lacking, particularly outside the surroundings of wilderness areas (Morris et al., 2017).

We surveyed forest owners and government employees using a standardized questionnaire to reveal the best supported control measure for pine stands in El Salvador affected by bark beetles. We included an open question to quantify the causes of the outbreak given by respondents. We analysed the influence of various factors (attitude towards the bark beetle, age, sex, education, stakeholder group, i.e. forest owner/government employee, outbreak causes and self-reported knowledge about the bark beetle) on four alternative control measures (chemical control, controlled burnings, salvage logging and stand thinning) applied to small or large areas.

2. Methods

2.1. Bark beetle context

El Salvador is the smallest country in Central America (21,000 km^2). It is estimated that the country has lost 85% of its forest cover since the 1960s (Crespin and Simonetti, 2016; Hecht et al., 2006). Most of the native forests have been transformed to agricultural land and silvopastoral and agroforestry systems, such as coffee plantations (Richards and Méndez, 2014). Forests in El Salvador mostly belong to private owners, who extract firewood and building timber, but whose income generally does not rely exclusively on pine wood. Detailed evidence-based forest management plans are lacking for the majority of forests in El Salvador (Mejia and Orr, 2015). Starting in 2015, a bark beetle outbreak affected a cumulative volume of about 20,500 m^3 of pine timber, concentrated in the provinces of La Unión and Morazán (MARN, 2016). Major drivers of this outbreak include drought stress caused by a warmer and drier climate, and fires, which are sometimes used to induce land-use changes, such as replacing native forests with plantations (González and Veblen, 2007).

The main bark beetle species causing the outbreak in El Salvador belong to the genera *Dendroctonus* (i.e. *Dendroctonus frontalis* and *Dendroctonus valens*) and *Ips* (i.e. *Ips grandicollis*, *Ips calligraphus,* and *Ips bonanseai*), and colonize predominantly Oocarpa pines (*Pinus oocarpa*), but also Caribbean pine (*Pinus caribaea*). Because of the lack of guidelines on how to best manage stands affected by bark beetles, a large variety of control measures have been applied (MARN, 2016). These control measures were applied unsystematically and produced mixed outcomes, ranging from control measures ineffective in decreasing population densities of bark beetles (e.g. cut-and-leave, chalking, and the application of surface-active insecticides) to effective control measures (e.g. salvage logging, with removal or complete burning of infested trees and logging residuals) (MARN, 2016). However, best management guidelines for bark-beetle-affected stands in El Salvador are still lacking.

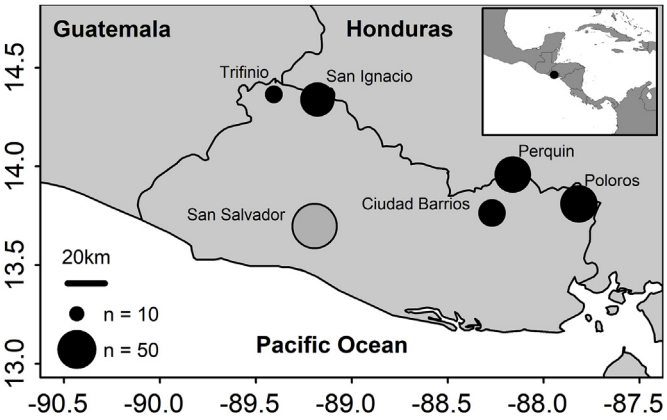

Fig. 1. Towns in which questionnaire surveys on bark beetles and their management in El Salvador were conducted. Point sizes correspond to the number of respondents. Local forest owners (n = 160) in five towns close to the Honduran and Guatemalan borders (black lines) and government employees (n = 82) in the capital, San Salvador, filled out the questionnaire.

2.2. Questionnaire survey

We conducted a standardized questionnaire survey directed at forest owners in towns distributed in northern El Salvador (Fig. 1) and at government employees in the capital. At each location, we conducted small informal workshops on bark beetle outbreaks and management. Questionnaires were distributed at workshops prior to the beginning and were filled out and retrieved before the workshops began.

Following McFarlane et al. (2006), our questionnaires quantified how important respondents rated the bark beetle topic to themselves [i.e. 'How important is the bark beetle topic to you personally?'; ranging from (1) very unimportant to (5) very important], self-reported knowledge about the bark beetle [i.e. 'How high would you rate your personal knowledge about bark beetles?'; ranging from (1) very low to (5) very high], and self-reported dependence on economic returns from forests [i.e. 'How much does your income depend on the forest sector?'; ranging from (1) very little to (5) very much], demographic parameters, attitude towards the bark beetle, and their preference for different bark beetle control measures (following McFarlane et al., 2006). To quantify whether respondents have a positive or negative attitude towards the bark beetle, we selected eight evaluative statements (Table 1) on a five-point Likert scale (Müller and Job, 2009).

Education was coded into eight increasing levels of educational degree by attainment, namely Primaria, Secundaria, Bachillerato general, Bachillerato técnico, Técnico, Profesorado, Ingeniería, and Licenciatura. We also used eight evaluative statements on a five-point Likert scale to reveal preferences for different bark beetle control measures of the respondents from 1 (low preference) to 5 (high preference) (McFarlane et al., 2006). These control measures included controlled burnings, use of chemicals, salvage logging and stand thinning, and were considered for small areas and large areas separately. We included an open question ('In your opinion, what are the three most important reasons for bark beetle outbreaks?').

2.3. Data analysis

All data analyses and statistical models were performed in R version 3.3.3 (www.r-project.org). The attitude of the respondents towards the bark beetle was computed by averaging the eight attitude items for each

Table 1
Attitudes of government employees and local forest owners from El Salvador towards the bark beetle. Results are based on questionnaire survey with 242 respondents. Statements were assessed on a five-point Likert scale, from 1 (totally disagree) to 5 (totally agree). Means (m) and standard deviations (SD) are given for the respective number of respondents (n).

Attitudinal statement	Forest owners			Government employees		
Overall (Cronbach's α = 0.71)	*n*	m	SD	*n*	m	SD
Positive statements (Cronbach's α = 0.62):						
The bark beetle…						
…helps to keep forests healthy.	149	2.3	1.3	81	1.8	1.0
…is important for forest rejuvenation.	150	2.4	1.3	77	2.2	1.2
…should have a right to exist in remote areas.	148	2.7	1.3	79	2.5	1.3
Negative statements (Cronbach's α = 0.72):						
The bark beetle…						
…should be controlled.	153	4.3	1.1	81	4.5	0.8
…is an ecological disaster.	150	3.8	1.3	79	3.3	1.3
…is a threat to biodiversity.	143	3.9	1.3	80	3.4	1.4
…results in substantial economic losses.	145	4.2	1.2	82	3.9	1.5
…is a serious threat to the existence of people.	149	3.4	1.4	80	3.0	1.3

respondent; inverse-coded items were back-transformed before averaging. In our study, a positive or negative attitude refers to a favourable or unfavourable personal assessment of the bark beetle, typically expressed as positive or negative evaluations, ranging from 1 (very negative attitude towards the bark beetle) to 5 (very positive attitude towards the bark beetle). We then estimated item reliability by means of Cronbach's α, provided by the function 'alpha' in the R package 'psych' (Cronbach, 1951). Cronbach's α measures the degree to which a set of items measures a single unidimensional latent construct (e.g. attitude towards the bark beetle). Values of $\alpha < 0.65$ indicate an unreliable measurement (Streiner, 2003). Attitude towards the bark beetle had an overall Cronbach's $\alpha = 0.71$, indicating reliable internal consistency.

The attitude towards the bark beetle was modelled in a linear model that included education, age, and subjective knowledge about the bark beetle as numerical predictors, and sex and forest owner or government employee as categorical predictors. We used a qualitative content analysis with an inductive approach (Mayring, 2014) to assign causes of bark beetle outbreaks given by respondents to each of four binomial response variables (yes/no); causes included 'mistakes in management', 'mistakes in policy-making', 'climate change', and 'fire'. The reliability of our category assignment was estimated by an intra-rater/inter-rater design (Cohen's K; Cohen, 1960). We randomly selected 10% of all causes given by respondents and repeated the assignment to the above-described categories again, once by the same person (intra-rater) and once by another person (inter-rater) who was not familiar with the data. The higher the agreement of dedicated categories was, the higher was the reliability (Cohen's K = 1 corresponds to 100% accordance). This procedure yielded K = 0.94 (inter-rater) and K = 0.74 (intra-rater), which indicated a robust category assignment (Cohen, 1960).

2.4. Statistical models

We modelled the presence of any of the four causes of bark beetle outbreaks given by participants (i.e. respondents mentioned at least one cause of the bark beetle outbreak) and the presence of each cause separately. We used binomial linear models with presence (0/1: no cause given/any cause given) as response variable and demographic variables, attitude towards the bark beetle, self-reported knowledge about the bark beetle and stakeholder group as predictors.

Preferences for different control measures were modelled simultaneously in one cumulative link mixed model provided by the function 'clmm' in the R package 'ordinal'. We used the scores of all control measures as the response variable and the type of control measures as a categorical predictor nested within the respondent to control for repeated measurements (Christensen, 2016). Furthermore, we added the preferred control measure extent (small/large areas), the attitude towards the bark beetle, subjective knowledge, education level, sex, age and stakeholder group as predictors. We also included the presence of any reason for the outbreak given (i.e. 'overall reason') in any of the respective categories (i.e. 'mistakes in management', 'mistakes in policy-making', 'climate change', and 'fire') and all different categories as binary variables in the model (i.e. preference ~ type of control measure + extent + attitude + knowledge + age + sex + education + forest dependence + stakeholder group + overall reason + management mistakes + policy mistakes + control-burnings + climate change + (1|id)). In addition, we included an interaction term of stakeholder and control method in the model to test whether preferences for control measures differed between different stakeholder groups. The interaction between control measure preference and stakeholder group was not significant and was therefore omitted from the final model.

We compared the preferences for different control measures by means of the function 'lsmeans' from the R package 'lsmeans' and 'glht' from the R package 'multcomp' with a simultaneous adjustment of p-values for multiple testing (Hothorn et al., 2008).

3. Results

Of the 350 questionnaires that were handed out, 242 were returned. Respondents had a mean age of 45 (SD = 14.5), 20% were female, 33% were government employees (corresponding to ~80% of all government employees working within the forest sector), and the remaining 67% were local forest owners from different towns (Fig. 1). Thirty-five percent had a university degree (i.e. 'Profesorado', 'Ingeniería', 'Licenciatura'). Local forest owners and government employees had similar educational levels and rated their subjective knowledge about the bark beetle as intermediate (3.2 ± 1.3). All respondents rated the bark beetle issue as of high personal importance (issue salience: 4.8 ± 0.5); the self-reported dependence on forest was rated only intermediate (2.4 ± 1.8) (Table 2).

Respondents had a slightly negative (2.23 ± 0.83) attitude towards the bark beetle in general (Table 1). Men had a significantly ($p = 0.037$, linear model) more positive attitude towards the bark beetle (2.25 ± 0.84) than women (1.97 ± 0.68), whereas education, age, knowledge, dependence on the forest and stakeholder group had no significant effect (Appendix S1).

Respondents with a higher educational degree named at least one correct reason for the bark beetle outbreak significantly more often than those with a lower educational degree (Fig. 2a). Furthermore, more highly educated respondents more often proposed climate change and mistakes in management as causes for the bark beetle outbreak. Respondents with a more positive attitude towards the bark beetle and those with higher self-reported knowledge about the bark beetle named 'fire' significantly more often as a driver of bark beetle outbreaks than other causes (Fig. 2b). Climate change was mentioned more often by government employees than by local forest owners as a reason for the outbreak (Fig. 2c). Mistakes in management were more likely to be mentioned by men than by women (Fig. 2d). All groups named mistakes in political decision-making equally often, i.e. there was no significant effect of any predictor variable on the presence of political mistakes among the given causes of bark beetle outbreaks (Fig. 2).

Respondents preferred beetle control measures on small areas than measures on large areas (Fig. 3). The preference for bark beetle control measures generally increased with increasing self-reported knowledge about the bark beetle but decreased with increasing level of respondent

Table 2
Predictors of attitude towards the bark beetle in El Salvador. Means (m) and standard deviations (SD) are given for the respective measures.

Variable	Operationalization	Measure	m ± SD
Education	Highest educational degree (rating from 1 to 8; low-high)	1 = Primaria (primary school; lowest), 2 = Secundaria/Básico, 3 = Bachillerato general, 4 = Bachillerato técnico, 5 = Técnico, 6 = Profesorado, 7 = Ingeniería, 8 = Licenciatura (university degree; highest)	4.9 ± 2.5
Self-reported knowledge	Subjective rating of knowledge about bark beetle by respondent	5-Point Likert scale, low to high	3.2 ± 1.3
Self-reported dependence on the forest	Subjective rating of the dependence of a respondent on economic return from forest	5-Point Likert scale, low to high	2.4 ± 1.8
Issue salience	Subjective rating of importance of bark beetle outbreak by respondent	5-Point Likert scale, low to high	4.8 ± 0.5
Government employee/ Forest owners	Noted according to workshop event	Binomial	160 forest owners, 82 government employees
Sex	Female/Male	Binomial	49 females, 152 males
Age	Number of years	Scale	45 ± 14.5

education level and increasing positive attitude towards the bark beetle. Respondents who named climate change as a reason for the bark beetle outbreak had significantly lower preferences for bark beetle control measures in general. Economic dependence on the forest had no effect on preferences for different control measures, and control measure preferences did not differ between government employees and forest owners.

Controlled burning and chemical control of bark beetle affected areas were significantly less preferred than thinning or salvage logging (Fig. 4). However, we found no differences in preferences for thinning and salvage logging or for controlled burning and chemical control.

4. Discussion

In our survey of the two main stakeholder groups involved in forest management in El Salvador – government employees and forest owners – both stand thinning and salvage logging were the commonly preferred measures for managing an ongoing beetle outbreak. As their common preferences align with recommendations based on scientific evidence, other bark beetle control measures that are being applied, such as controlled burnings and the use of chemicals, should be halted.

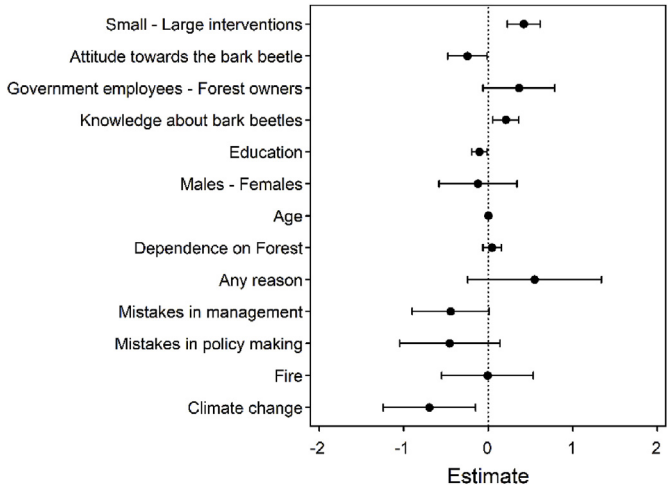

Fig. 3. Estimates and confidence intervals of cumulative link mixed model with preference for control measures [5-point Likert scale, from 1 (totally disagree) to 5 (totally agree)] as response variable and demographic variables, attitude towards the bark beetle, self-reported knowledge about the bark beetle, stakeholder group, extent of control measure, and reason for bark beetle outbreaks given by participants as predictors.

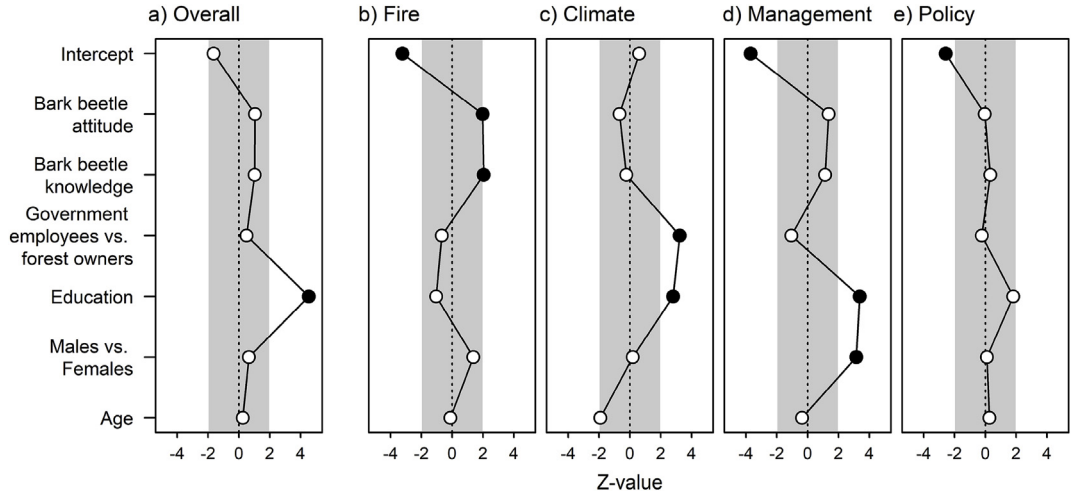

Fig. 2. Effect of demographic variables, attitude towards the bark beetle, self-reported knowledge about the bark beetle and stakeholder group on the reasons given for bark beetle outbreaks in El Salvador. Results are based on binomial models with the presence of a) any cause (overall model), b) fire, c) climate change, d) mistakes in forest management and e) mistakes in political decision-making as main reasons given for bark beetle outbreaks as response variable. Grey shading indicates range of non-significant values ($-1.96 < \text{z-value} < 1.96$); solid black lines are for illustrative purposes only and do not reflect trends.

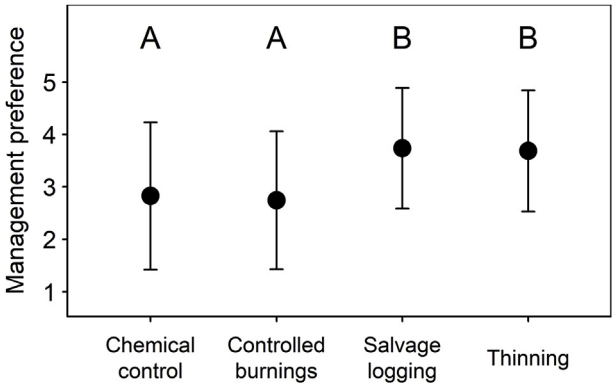

Fig. 4. Mean preference for different bark beetle control measures (5-point Likert scale, low to high) of 242 respondents. Significant differences, indicated by upper-case letters, are based on multiple comparisons with simultaneous adjustment of p-values. The model included preferences for control measures as response variable and demographic variables, attitude towards the bark beetle, self-reported knowledge about the bark beetle, as well as stakeholder group as predictors. Error bars indicate standard deviation (see Appendix S2 for full statistical results).

4.1. The importance of education

Those respondents of the questionnaire with a higher educational degree mentioned climate change as a reason for bark beetle outbreaks more often and indicated a lower preference for active outbreak control measures. These respondents possibly perceive climate change as inevitable, with little possibility of countering it through bark beetle control measures. In contrast to our findings, landowners in Virginia (USA) with a college degree were more willing to participate in preventive thinning of pine stands than those without a degree (Watson et al., 2013). The different attitude of the respondents in El Salvador might arise from the mixed outcomes of bark beetle control measures applied in their country to date, which could lead to scepticism toward the success of future measures (McFarlane et al., 2015). In addition, bark beetle control measures applied in El Salvador are mostly reactive and not preventive (MARN, 2016). Furthermore, highly educated individuals are typically better prepared to cope with natural disasters and thereby suffer lower negative impacts (Muttarak and Lutz, 2014). Thus, a low preference for bark beetle control measures might also reflect the greater serenity of highly educated individuals regarding bark beetle outbreaks. Indeed, expectations of forest recovery after bark beetle outbreaks tend to increase with education through a less fatalistic attitude, which in turn reduces the perceived need for control measures (Morris et al., 2018).

Earlier findings from Germany and Canada have shown that serenity gained through education might be related to more positive attitudes towards the bark beetle (McFarlane et al., 2006; Müller and Job, 2009). However, we did not detect any effect of education or self-reported knowledge on attitude towards the bark beetle in El Salvador. Besides general cultural differences, an explanation for these divergent results might be a higher ecological awareness of Canadians and Germans towards natural forest dynamics, particularly because of, e.g. periodic outbreaks of bark beetles in Canadian forests (Nikiforuk, 2011). We therefore recommend that the transfer of scientific knowledge of ecological forest dynamics (e.g. through standard media) be improved to provide a permanent link between advanced ecological understanding and its application by society to foster effective, sustainable forest management policies.

4.2. Bark beetle control measures

Questionnaire respondents preferred control measures applied to small areas rather than to large areas, which is similar to earlier findings in Canada (McFarlane et al., 2006). However, such a preference contrasts with the large scale of outbreak dynamics, as the strongest increase in bark beetle populations typically occurs when climatic conditions are suitable and forests are susceptible to attack (Morris et al., 2018; Seidl et al., 2015). Consequently, there is evidence that control measures applied consistently at large scales are more effective than control measures at small scales (Fettig et al., 2007). This divergence between the preference for small areas found in our study and the greater effectiveness when applied to large areas might be another reason for the mixed outcomes of the currently applied bark beetle control measures in El Salvador. Widespread salvage logging of trees weakened by natural or anthropogenic disturbances (e.g. windstorms, extreme drought and wildfires) has the potential to reduce the speed and extent of bark beetle outbreaks (Bentz et al., 2009; Schroeder and Lindelöw, 2002; Stadelmann et al., 2013). However, extensive salvage logging has significant ecological impacts with long-lasting effects (Lindenmayer et al., 2017) and has hence been recently debated controversially (Leverkus et al., 2018a). The preference for salvage logging of beetle-affected trees found in our study is in line with common post-outbreak management strategies performed around the world (Leverkus et al., 2018b). The major justification for salvage logging globally is to recover some economic returns from timber affected by bark beetles (Müller et al., 2018). However, the lack of an effect of personal dependence on forest resources on the preference for any bark beetle control measures (Fig. 3) suggests that respondents from El Salvador have other major motivations for bark beetle control measures. This finding also contrasts the higher preference for bark beetle control measures shown by those who own forest for income or investment (Watson et al., 2013). These contrasts illustrate the importance of carefully evaluating the economic justifications for salvage logging in general. Besides economic reasons, motivations for salvage logging in El Salvador likely include pest control, aesthetics and restoration of affected forest stands (e.g. Müller et al., 2018). Such management goals support the application of new bark beetle control measures that combine biodiversity protection, pest control and economic returns (instead of landscape-wide salvage logging), such as bark scratching of disturbance-affected trees, which reduces bark beetle populations while maintaining most non-target biodiversity and high recreational values (Thorn et al., 2016; Hagge et al., 2018). Bark scratching might be particularly feasible as most bark-beetle-affected trees are concentrated in small groups and easy to reach (MARN, 2016).

The use of chemicals and controlled burnings were largely ineffective and disfavoured by respondents. Chemicals are ineffective because they are often surface active and therefore do not affect bark beetles in their galleries (MARN, 2016). Controlled burnings generally do not reach the intensity needed to kill bark beetles in logging residuals, but instead weaken living pines and make them more susceptible to future bark beetle attack (Billings et al., 2014). For these reasons, the lower preference for these two methods by both stakeholder groups is in accordance with scientific evidence of the inefficacy of these methods in controlling bark beetle outbreaks (Fettig et al., 2007; Kulakowski, 2016; Vega and Hofstetter, 2015).

In summary, the control measure preferences of government employees and forest owners match scientific evidence for the effective control of bark beetle outbreaks but are in discordance with the variety of methods currently applied by local communities in El Salvador. The use of these ineffective methods by local communities might be caused by a high variability in their preferences. Successful bark beetle control measures should hence consider the input of all local communities involved (Flint, 2006). Coalitions could be formed to generate a united voice on bark beetle management (Parkins and MacKendrick, 2007). Other explanations for this divergence in control measure preference and control methods used might simply be insufficient communication between stakeholders and the lack of clear policy. Communication among the various stakeholder groups and forest managers and bottom-up participation have been identified as key components of effective

management plans (Flint, 2006). By contrast, top-down approaches, where local communities are not engaged in the management of their own resources, could fail owing to the loss of trust in governmental institutions (McFarlane et al., 2012). We hence recommend that management of bark beetle outbreaks in El Salvador and elsewhere should involve local communities.

5. Conclusions

Ensuring the long-term sustainable management of forests in El Salvador requires coordinated environmental management and policy making that anticipates the possibility of extreme events. The general preferences of forest owners and government employees for beetle control measures and the alignment of their preferences with existing scientific evidence represents a strong basis for setting common management strategies. We recommend that beetle-infested trees as well as trees weakened by fire, drought or other factors should be extracted to minimize the effects of an ongoing outbreak. In addition, careful, long-term forest planning must guide actions that are undertaken immediately after logging and thereafter to increase the ecological resistance and resilience to subsequent natural disturbances. Actions aimed at increasing the heterogeneity in species composition and stand structure, such as reforestation with multiple species and periodical stand thinning, should reduce the susceptibility of the forests to insect outbreaks and natural disturbances in the future. Also, controlled burnings and the use of surface-active chemicals in El Salvador must be abandoned.

As our results show, a greater knowledge about the causes and implications of bark beetle outbreaks is often associated with a preference for the most effective management strategies. These findings may help to improve management responses to natural disturbances in general. For instance, continuous capacity building should be a centrepiece of forest policy, such that forest owners are trained to manage forests for increased resistance and resilience to natural disturbances in general. Communication channels among multiple stakeholders must be built and maintained in the long term so that common decisions and appropriate policies can be implemented swiftly in case of emergency situations. This could be achieved, for example, through capacity-building workshops and by making scientific evidence available to the public.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2018.11.032.

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